High Reflectivity Broad-band Silver Coating

Surface Optics Corporation

Balasubramanian Kynjthapatham, JPL - COTR

David Sheikh, SOC – PI

Silver Coatings For Space Telescopes

- Future space telescopes may be very large (possibly 4+ meter segments)
- SOC uses novel moving evaporation source technology, coating process scalable to ‘practically’ unlimited size.
- Technical Approach – Improve upon the LLNL protected silver design, based on lessons learned from Kepler

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Future Silver Coatings

- SOC's current 3-meter motion-controlled evaporation process scalable to larger sizes
- Improved UV performance possible with material selection and improved process control
- Better coating stress management and coating uniformity offer the possibility of 20-layer (or more) designs.

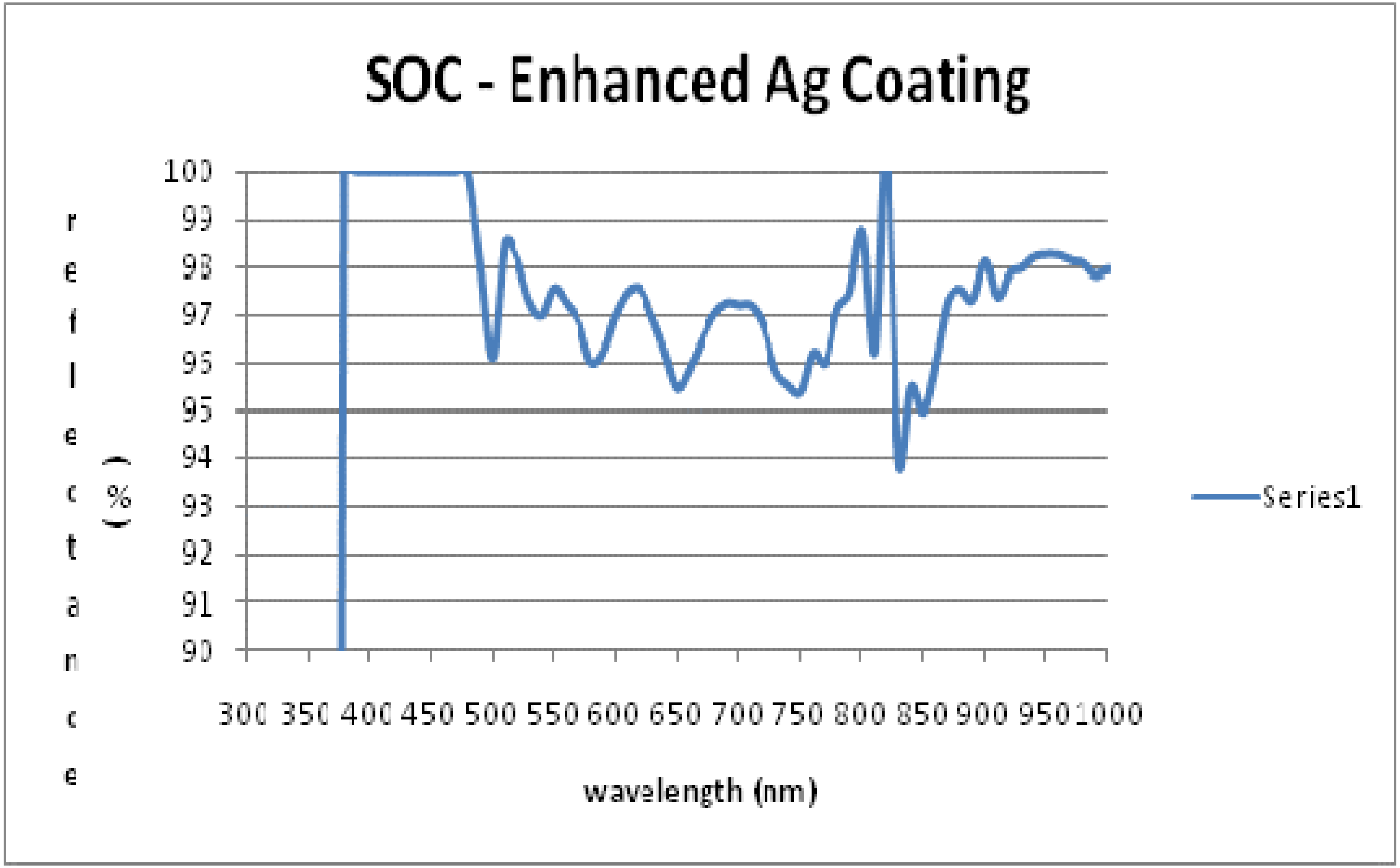
Silver Coating – Kepler Primary

Telescope Design

- We currently build our coatings to ‘fit the telescope’.
  - Coating uniformity (wavefront requirement)
  - Coating temperature (limited by structure, adhesives, etc.)
  - Environmental exposure (terrestrial, space radiation, etc.)
- Maybe? …future telescopes should be built to <u>fit the coating</u>.

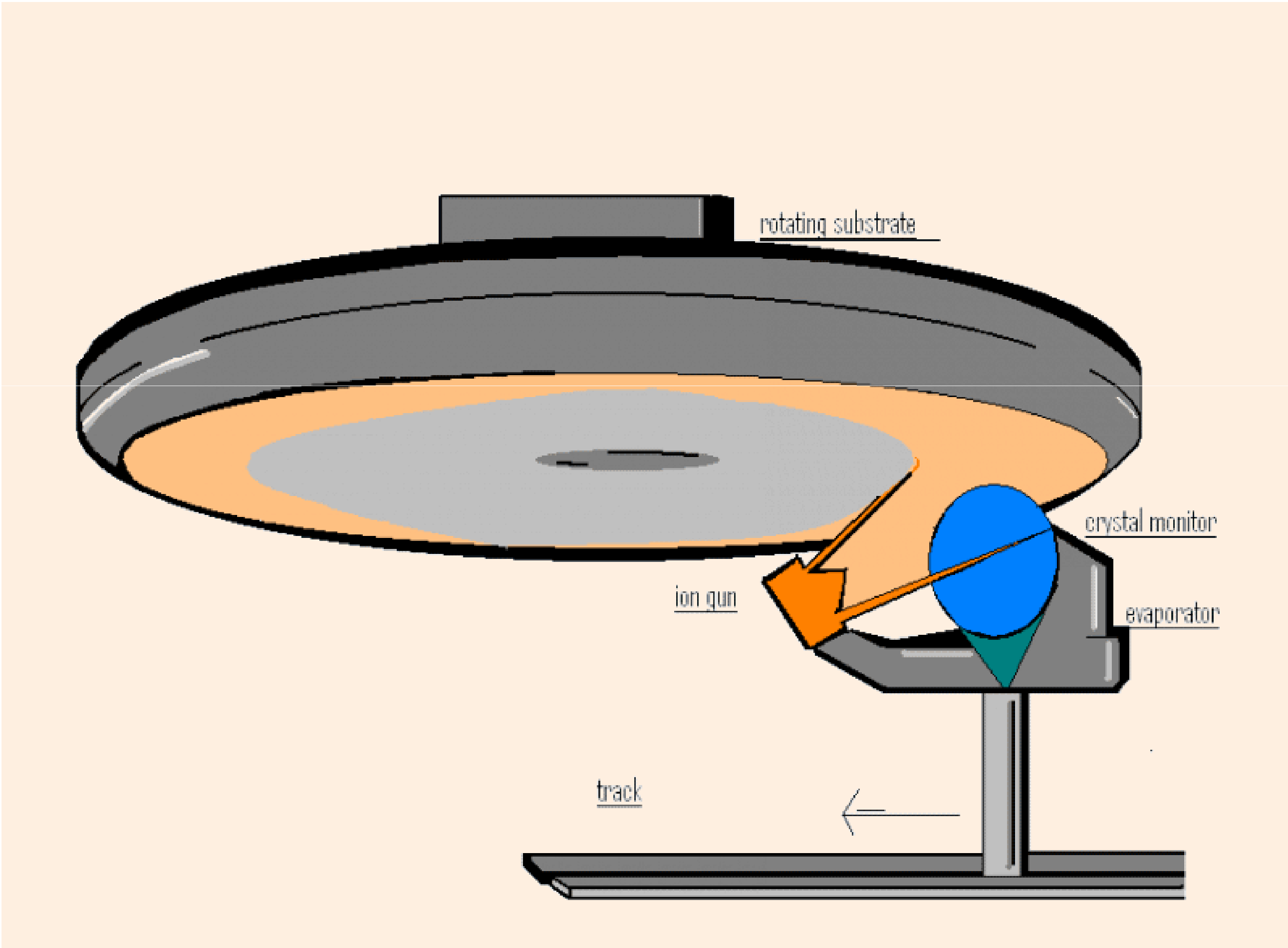
Silver Requirements For Future Space Telescopes

- Reflectance greater than 95% from 360-nm to 25,000-nm?
  - Comment: Difficult to meet requirements in far IR with enhanced R designs because most enhancement layers absorb energy in this region.
- Mirror size 2-5 meters in diameter, or hex segments
  - SOC's motion technology scalable to ANY size.
- Coating stress ?
  - Optimize for minimal stress and use realistic value to DESIGN large, lightweight telescope.
- Space radiation ?
  - Remove requirement by shielding mirrors?
- Ground storage and environmental?
  - Design telescope enclosure for long-term storage?
- Space thermal cycling?
  - Not usually a problem.


SOC - Enhanced Ag Coating
100
99
98
97
96
95
94
93
92
91
90
reflectance (%)
300 350 400 450 500 550 600 650 700 750 800 850 900 950 1000
wavelength (nm)
Series1

SOC’s 3.3-m coating chamber

Animation of motion system



Future 6-meter chamber with multiple evaporation sources

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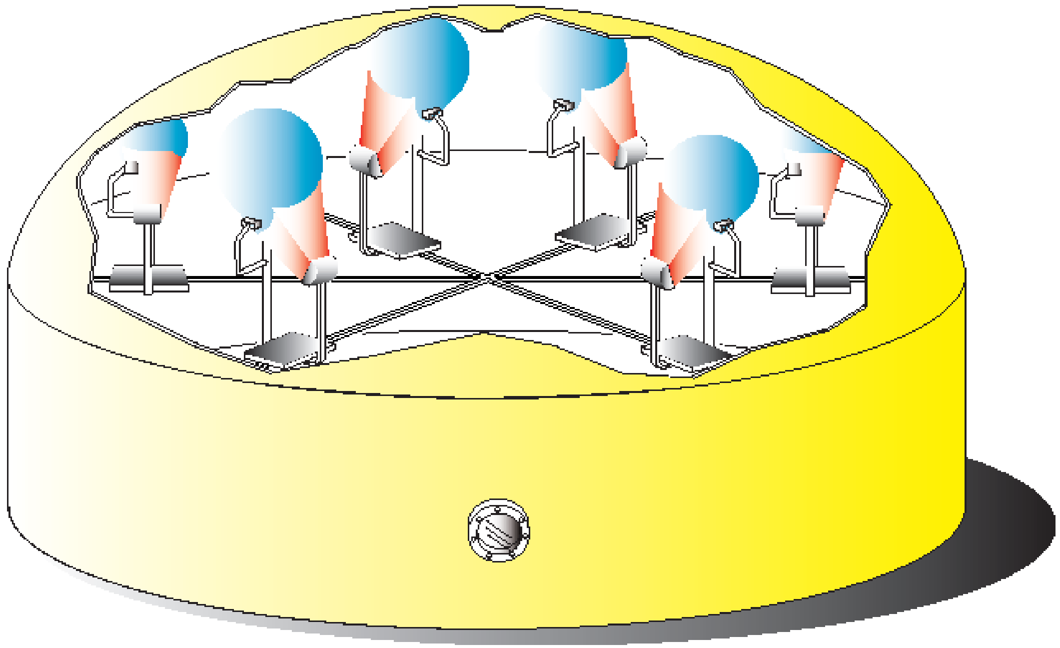


LLNL & Kepler Coating Designs

- Basic Protected Silver

Si_3N_4
Ni-CrN_x
Ag
Ni-CrN_x
Mirror Surface

- Protected & Enhanced

L-Oxide	Reflection Enhancement
H-Oxide	
L-Oxide	
H-Oxide	
L-Oxide	
Si_3N_4	Protected Ag
Ni-CrN_x	
Ag	
Ni-CrN_x	
Mirror Surface	

LLNL design - processing problems for large optics (Kepler Lessons)

- Precise deposition of 5 A of NiCrNx difficult over large areas.
- SOC’s motion control deposition system not adequate for 5 A deposition without modifications.
- N+ bombardment of NiCr to make NiCrNx removes NiCr (had to compensate by adding extra NiCr to outter radial positions).
- Si3N4 easily contaminated with background gas (requires exceptional vacuum). Need for UHV slows cycle time and test runs.
- Si3N4 has high index and reduces Ag reflectance

Why LLNL protection works?

- NiCrNx
  - Prevents Ag from reaction with S+
  - Promotes adhesion between Si_3N_4 and Ag
- Si_3N_4
  - Protects Ag from O+ during oxide deposition
  - Protects Ag from S+ and other chemical attack
- SiO_2/Ta_2O_5 pairs
  - Protects surface from scratching
  - Enhanced reflectance in blue and UV
  - Causes absorption in long IR

IAD process for making Si_3N_4 from Si

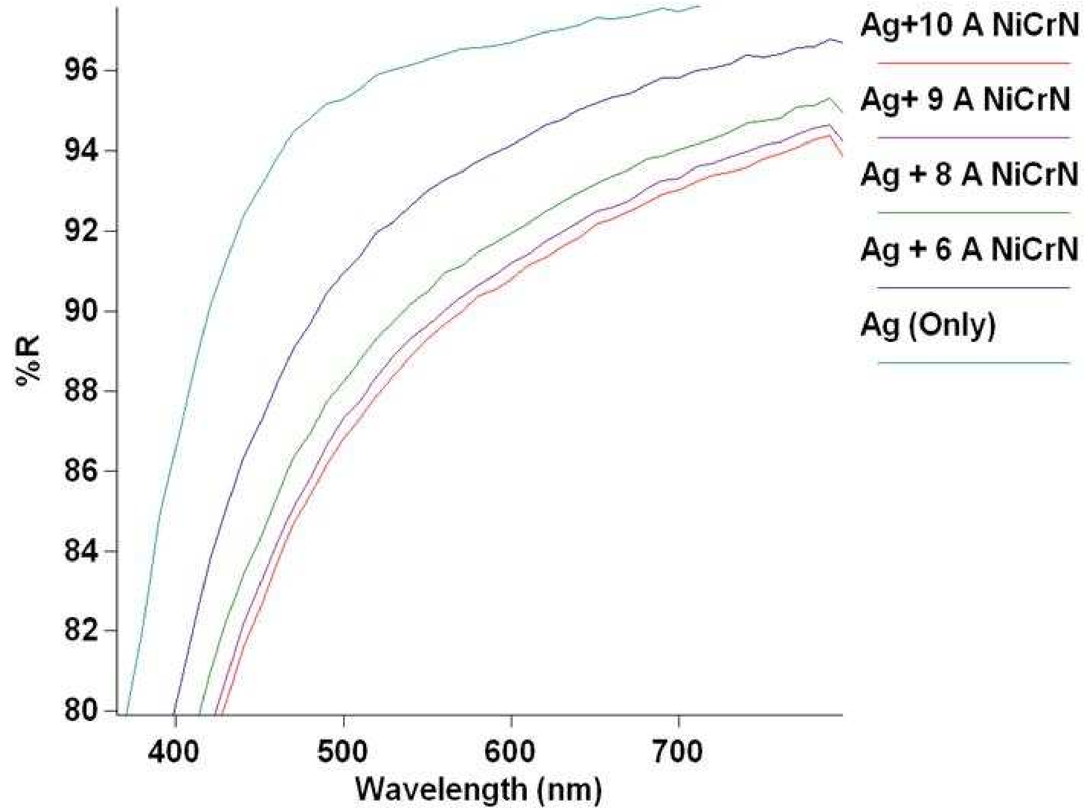
- Requires low vacuum to fabricate
- Doesn’t adhere well to Ag without NiCrNx under-layer
- High index and high short-end absorption lowers blue/UV reflectance
- Protects Ag from oxygen ion bombardment during deposition of oxide pairs

Opportunities for LLNL design improvement

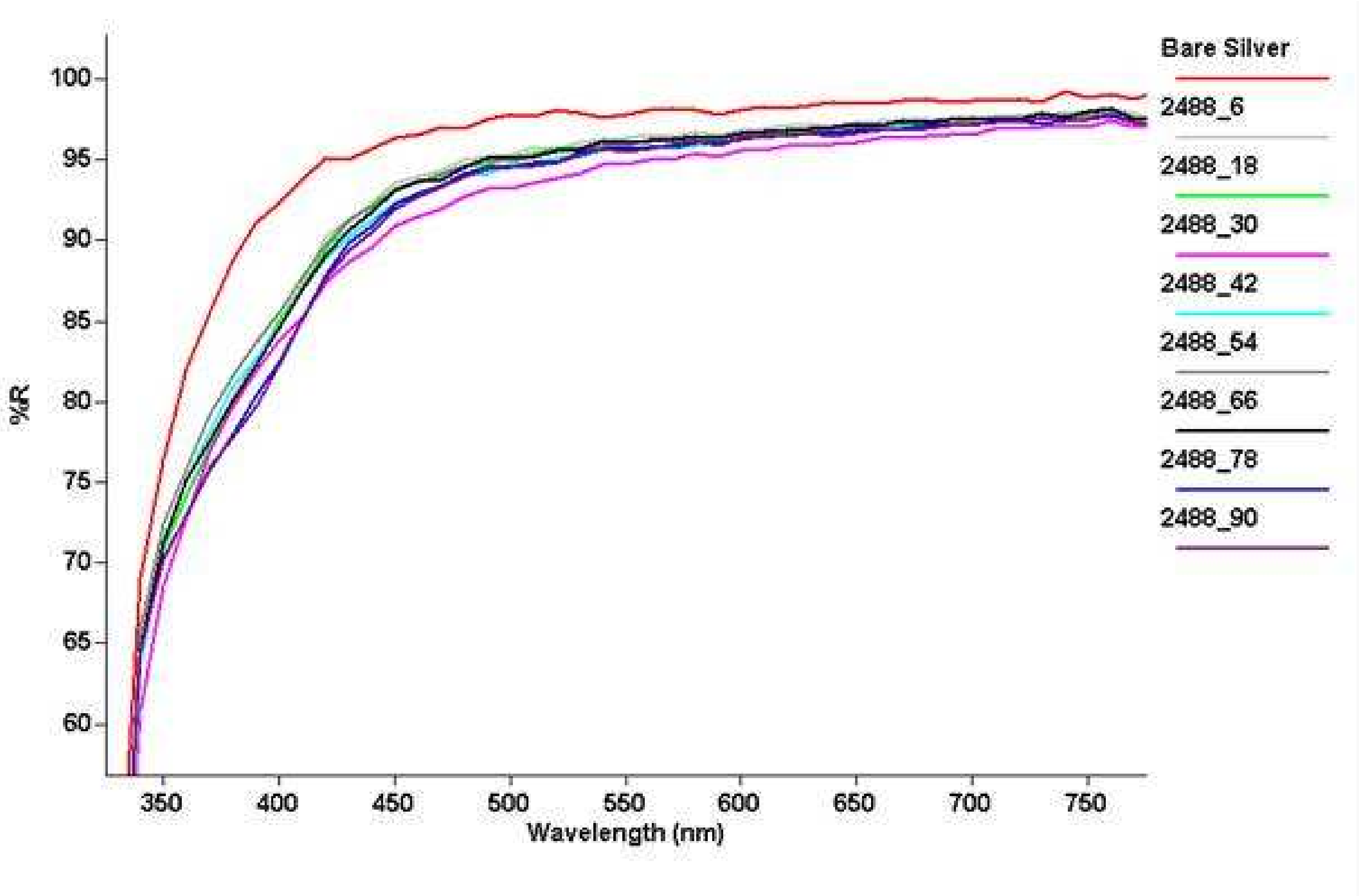
- Reduce NiCrNx to minimum required thickness
  - Improve motion-control deposition process for ultra-thin NiCrNx ‘layer’.
- Find alternative material to Si_3N_4 (O+ barrier)
  - Adherent to Ag by itself (no NiCrNx required)
  - Low index (n)
  - Low absorption (k) below 500-nm
  - Barrier to oxygen ions (note: Ag noble but still damaged by O+)

Effect of NiCrN thickness on Ag reflectance

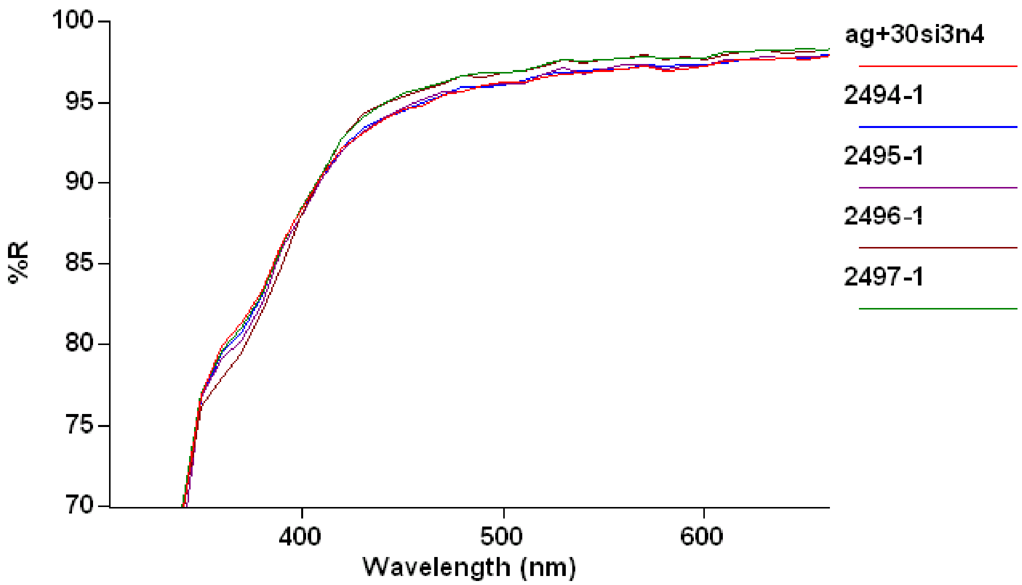
- Thickness is critical for durability
- Thickness is difficult to control over large area
- Highly absorbing in blue and UV



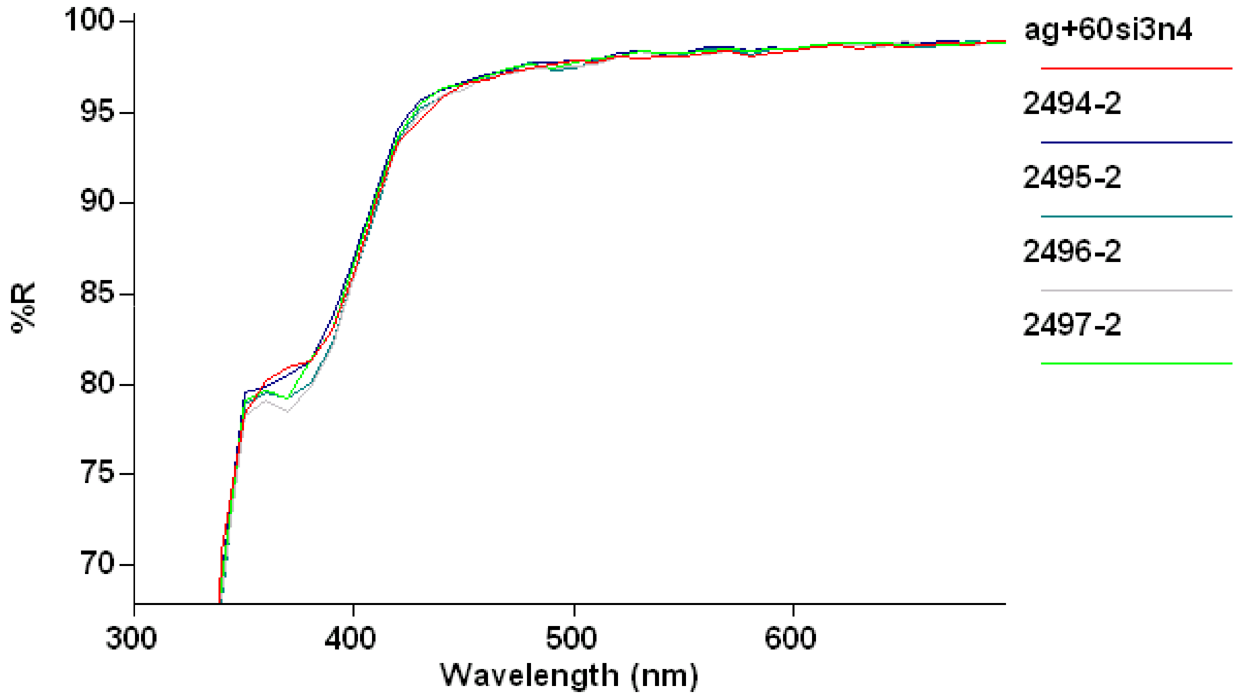
5 angstroms NiCr deposited (2-m diameter) on Ag with SOC upgraded motion system (completed in Phase I)



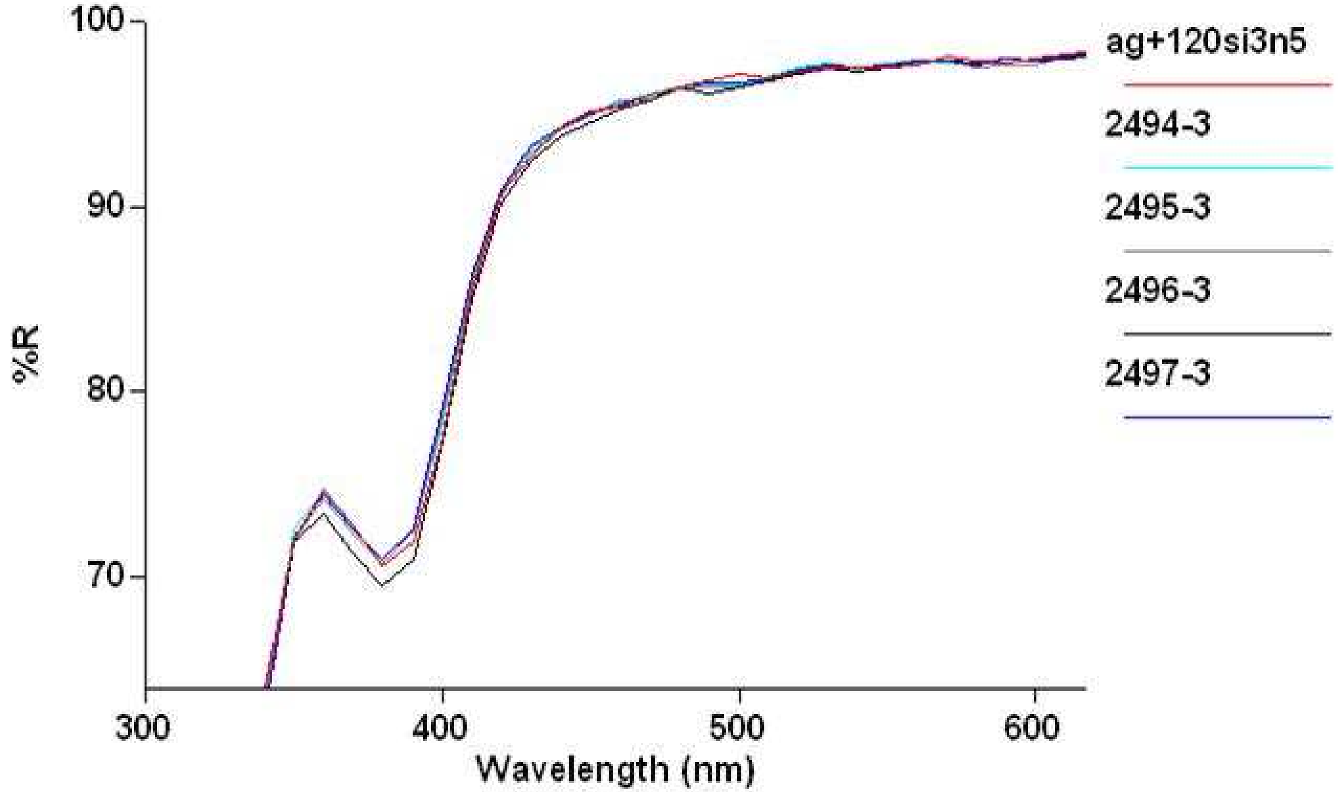
30 angstroms of Si3N4 (O+ barrier)



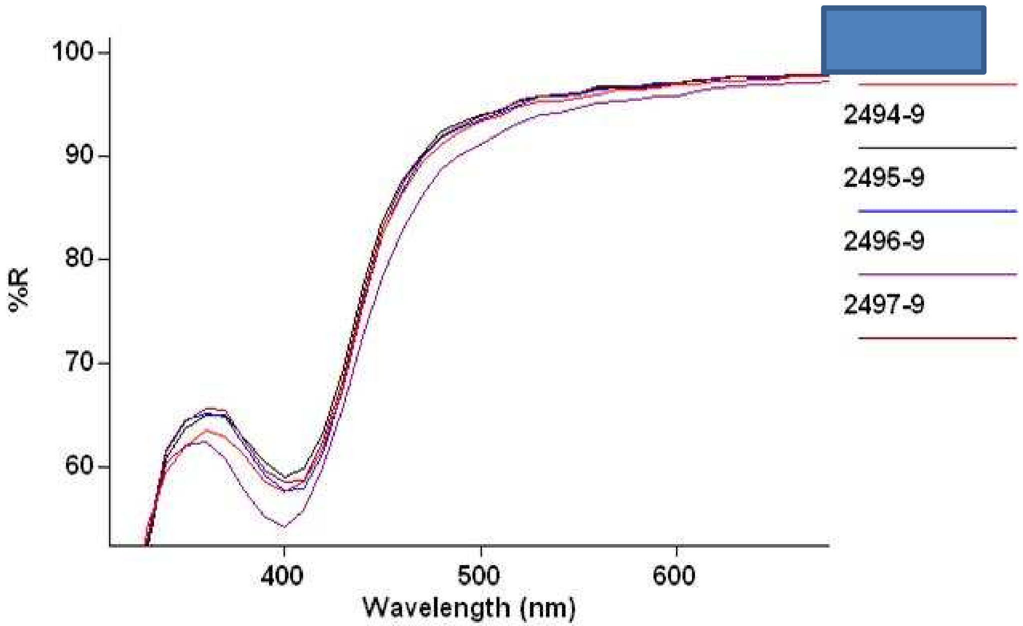
60 A Si3N4 (oxygen barrier)



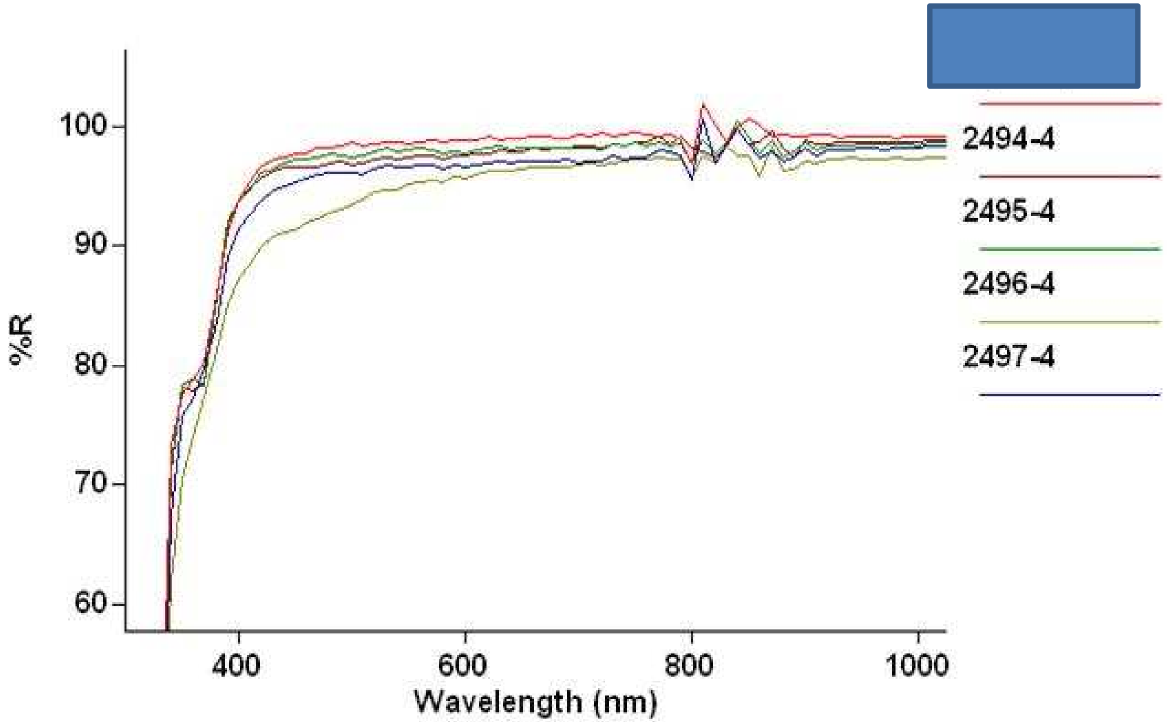
120 A Si3N4 (O+ barrier)



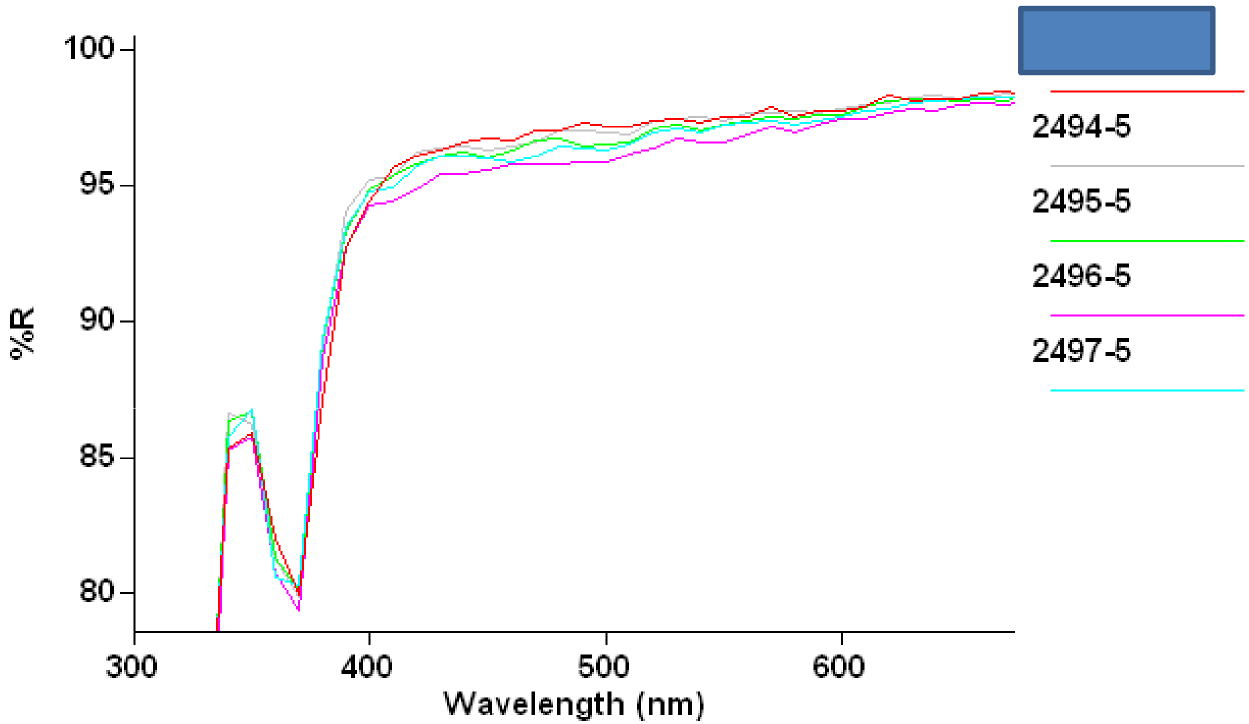
120 A of AX1 (candidate O+ barrier)



120 A of AX2 (Candidate O+ barrier)



600 A of AX2 (candidate O+ barrier)



Other opportunities to improve?

- Design future telescope to ‘carry’ a specific coating rather than designing a coating to work with a particular telescope design
  - Remove space radiation requirements by properly shielding the mirrors with a telescope housing
  - Increase allowable coating stress by increasing the weight of the mirrors if necessary (allow the coating design to determine the necessary weight of the mirror, rather than the other way around)
  - Design ground storage protection into the telescope structure, to reduce need for “ultra-durable” coating (N_2 purging system built into telescope?)

Conclusions

- An improved silver coating process is feasible by;
  - Improving process control to minimize NiCrNx layer thickness (cluster density)
  - Choosing an oxygen barrier with better optical properties and better natural adhesion to silver
  - Improve the ability to deposit precise layers over large areas, with reduced coating stress
  - Design future telescopes ‘from the coating backward’; environmental requirements, etc.